

METHOD OF STORING SOLAR ENERGY

5 **THIS APPLICATION IS A CONTINUATION-IN-PART APPLICATION OF
U.S. PATENT APPLICATION S.N. 10/091,066 FILED MARCH 5, 2002, WHICH IS
CURRENTLY PENDING, WHICH IS IN TURN A CONTINUATION OF
PCT/EP00/08649, FILED 09/05/2000, WHICH CLAIMS PRIORITY OF GERMAN
PATENT APPLICATION 199 42 398.9 FILED 09/06/1999.**

FIELD OF THE INVENTION

10 The invention relates to a method of storing solar energy in conjunction with reducing
the presently existing excessive atmospheric carbon dioxide (CO₂) level which is believed to
cause undesirable changes in the earth's climate.

15 This climate change is also believed to result from the increasing world energy
demand. Thus, the world energy requirements have been met in the past essentially by
combustion of a regrowable fuel such as wood. However, as a consequence of the
industrialization, which has continuously kept increasing since about 1850, the use of non-
regrowable fossil fuels like coal, oil, natural gas etc. has been steadily rising in order to meet
20 the increasing energy demands.

DESCRIPTION OF THE PRIOR ART:

25 As a first consequence of the aforementioned situation, exhaustion of the readily
accessible sources of the fossil fuels has become foreseeable. Consequently, substitution of
the fossil energy sources by regrowable energy sources is considered desirable again in more
recent times. For example, bioalcohol from agricultural source has been added to gasoline for

driving automobiles; in the same vein, Diesel fuel has been replaced with rape-seed oil. Also, charcoal, which is produced from trees or wood, or plant coal has been proposed as fuel in US Patent No. 4,318,710 issued to M. Pilipski on March 9, 1982, as well as the coal-like products obtained from agricultural waste or paper sludge in US Patent No. 4,272,322 issued to M. Kobayashi on June 9, 1981. Gaseous fuel in the form of synthesis gas, which constitutes a mixture of carbon monoxide and hydrogen, has been shown to be obtainable from organic compounds such as wood as well as other biomasses, see US Patent No. 3,942,956, issued to S. Ito on March 9, 1976, or from agricultural waste as shown by US Patent No. 5,707,762, issued to W. Johnssen on January 13, 1998. Pyrolysis and gasification also yield gaseous fuel from agricultural waste according to German Published Patent Application No. 196 18 213, published on November 13, 1997, in the name of Hugo Petersen Company for Process-technical Plant Construction, as well as International Published Application No. WO 00/06671, published on February 10, 2000, in the name of Stichting Energieonderzoek Centrum Nederland (Dutch Stichting Energy Research Center). According to German Published Patent Application No. 40 35 927, published on May 14, 1992, in the name of Battelle Institute, Frankfurt/Germany, nuclear reactors, electrical energy, wind energy, water flow energy as well as biomass combustion energy can be used for producing hydrogen as an energy source by thermal decomposition or pyrolysis of hydrocarbons or biomass in the absence of air; the carbon, which is also formed in such process is provided for non-energetic use, stored or deposited. German Published Patent Application No. 35 26 879, published on February 5, 1987, in the name of H. Mächtling, Xanten, Germany, teaches storing combustible materials in an inert gas atmosphere for preventing ignition of such material.

According to present understanding, it is a further consequence of the aforementioned situation that since about 1850, due to the increasing combustion of fossil and other carbon containing energy sources, there is generated and introduced into the atmosphere a greater amount of CO₂ than the amount of CO₂ which is removed from the atmosphere due to the

assimilation by plants and other processes. As a result, the amount of CO₂ which is present in the atmosphere, has been continuously increasing since that time. In parallel therewith, the absorption of long-wavelength radiation (heat radiation) by the earth's atmosphere has also been increasing correspondingly. Thereby, there is caused a greenhouse effect which has caused increasing atmosphere temperatures and thus harmful climate changes on the earth. In respect thereof, a basic climate agreement has been concluded at the UN climate conference in Rio de Janeiro in 1992, however, no international agreement could be found with regard to the extent of the required reduction in the atmospheric CO₂ level at the following conference in Kyoto in 1997. A reduction by 25% of the 1990 value until 2005 and a further reduction until 2015 were considered necessary. With reference thereto, there was also proposed a trade in emission rights in order to thereby achieve a balance between nations which realize higher and lower atmospheric CO₂ level reductions, respectively.

The aforementioned substitution of fossil energy sources by biomass-based energy sources results in a reduction of the use of the fossil energy sources. However, such reduction does not effect a reduction in the atmospheric CO₂ level in view of the fact that both energy sources contain carbon the combustion of which constitutes the actual energy source. In fact, the carbon present in the biomass based energy sources derives from the atmosphere and has been integrated into the biomass as a consequence of assimilation during plant growth. Therefore, combustion of biomass-based energy sources will simply result in returning into the atmosphere the CO₂ which has been removed from the atmosphere in the first place. In the material balance a reduction in the atmospheric CO₂ level thus cannot be achieved.

A certain reduction in the atmospheric CO₂ level may be achieved by reducing the combustion of carbon containing energy sources, for example, by improving on the heat insulation of buildings, by increasing the efficiency of power generating engines, by utilizing solar energy using solar cells or solar collectors as well as by utilizing the energy of wind energy and hydroelectric power. While all of these energy generating possibilities do effect a

reduction in the CO₂ generation, the reduction is effected only to a limited extent such that the desired reduction in the atmospheric CO₂ level can not be achieved thereby.

A lasting integration of atmospheric CO₂, however, occurs in long-lived wooden products made of wood of trees harvested from forests. When forest wood is harvested by means of clear-cutting, the assimilation power of the related forest will be lost and correspondingly also there will no longer exist any CO₂ assimilation. Regrowing the related forest will require decades to generate an assimilation power corresponding to the original forest and will be effective for reducing the atmospheric CO₂ level to full extent only after the full regrowth period.

During sustainable forestry, i.e. in the event that wood is harvested from a given forest during a harvesting operation only to the extent as such wood will regrow during a following regrowth period, the mean forest assimilation power and its mean CO₂ binding power will be maintained. A reduction in the atmospheric CO₂ level, however, then will occur only in the extent of the lower wood harvest (as compared to the aforementioned clear-cutting) and the extent to which the harvested wood is processed to yield long-lived wooden products.

While it would be conceivable to effect the required reduction of the atmospheric CO₂ level by planting new forests, it may be considered doubtful whether the areas required therefore would be available. Furthermore, it would take decades before such new planted forests achieve full assimilation power so that the desired effect cannot be achieved within the required short period of time.

Thus, all of these known measures are neutral with respect to the atmospheric CO₂ level only in the most favourable cases. However, the known measures are unable to reduce the presently existing CO₂ level which is present in the atmosphere or originates from other sources.

DISCLOSURE OF THE INVENTION

Therefore, with the foregoing in mind, it is a primary object of the present invention to provide a new and improved method of storing solar energy which method is not afflicted by the aforementioned drawbacks and limitations of the prior art methods.

Another and more specific object of the present invention aims at eliminating the drawbacks of the prior art methods and, in particular, at providing a new and improved method of storing solar energy while simultaneously effecting a reduction in the atmospheric CO₂ level.

Furthermore, an important and still more specific object of the invention aims at providing a method of storing and delaying use of the stored solar energy in a manner such that the balance between the rate of CO₂ removal from the atmosphere and the rate of release of CO₂ into the atmosphere is kept at an atmospheric CO₂ level below the level causing the undesired greenhouse effect.

Now, in order to implement these and still further objects of the invention, which will become more readily apparent as the description proceeds, the method of the present development is manifested, among other things, by the following method steps:

Producing photosynthetically an amount of biomass capable of forming biomass coal;
harvesting the amount of photosynthetically produced biomass;
regrowing, between two successive harvesting operations, an amount of biomass which corresponds to the harvested amount of photosynthetically produced biomass;
converting the harvested amount of photosynthetically produced biomass into biomass coal;
and durably and retrievably storing the biomass coal in order to thereby reduce the

atmospheric CO₂ level by an amount of CO₂ which is equivalent to the amount of carbon present in the stored amount of biomass coal.

Preferably, a sequence is carried out entailing a multiple number of the steps of harvesting and regrowing the harvested biomass, converting the harvested biomass into biomass coal and storing the biomass coal in order to thereby achieve a balance between the rate of CO₂ removal from the atmosphere and the rate of CO₂ release into the atmosphere at an atmospheric CO₂ level below a level which causes the undesired greenhouse effect.

A level of atmospheric CO₂ considered as ineffective for causing an undesired greenhouse effect may be, for example, the level agreed upon during the initially mentioned Kyoto conference.

In a further development of the inventive method, either a fraction of the biomass coal or a fraction of the stored biomass coal is converted into energy or an energy source with concomitant CO₂ release to the atmosphere, provided that the increase in the atmospheric CO₂ level caused thereby is limited to an amount which is lower than the amount of CO₂ equivalent to the carbon present in the stored biomass coal.

An advantageous embodiment of the inventive method relies upon selecting wood from a preferably sustainably managed forested area as the photosynthetically formed biomass, harvesting the wood, converting the harvested wood into charcoal and durably and retrievably storing the thus produced charcoal in the aforementioned manner.

The forested area may constitute an isolated forested area, a number of separated forested areas, the entire forested area of a given geographical region or a given country or number of countries.

DESCRIPTION OF PREFERRED EMBODIMENTS

Turning now specifically to Example 1, biomass coal is produced from photosynthetic biomass in known manner such as pyrolysis, dry distillation or thermal decomposition in the absence of oxygen. The biomass is harvested from a planted or forested area. Such biomass coal may constitute, for example, charcoal which is obtained from wood harvested from a forested area. The biomass coal is infed into a bunker plant, for example, a subterraneous cavity such as present in coal, ore or salt mines or the like as well as known above-ground constructions. The biomass coal storage may involve time periods of up to 20 years or even more. In order to prevent ignition or oxidative degradation, the biomass coal is preferably stored under non-ignitable protective gas having a density greater than air such as CO₂ or, if desired, a rare gas. Each bunker plant advantageously may be equipped with known means in a manner such that the stored biomass coal is protected from water ingress and/or excess temperatures. A number of mutually independent biomass coal reservoirs may be provided in a given bunker plant.

The carbon content of the biomass coal, which is formed from the photosynthetically produced biomass, originates from the assimilation of atmospheric CO₂ by the plants under the action of sunlight. According to the stoichiometric relationship, 12 parts by weight of pure carbon correspond to 44 parts per weight of CO₂; thus, 100 kg of biomass coal which consist of 100 percent carbon and which are stored as described hereinbefore, correspond to the removal of 366.7 kg of CO₂ from the atmosphere.

Considering now wood as an example of photosynthetically produced biomass, such wood is preferably obtained from a predetermined forested area managed by sustained forestry. The predetermined forested area yields an annual harvest of 1 ton of wood which is regrown during an annual growth period between two successive wood harvests. The entire amount of 1 ton of wood is converted into 350 kg of charcoal containing, on the average, 85 percent of

carbon (Römpf, Chemistry Encyclopedia 1983, p. 1737), i.e. 298 kg of carbon. Due to the storage of the entire amount of charcoal (neglecting any amount of CO₂ which may be formed during the harvesting, converting and storing operations), the equivalent amount of CO₂, namely 1.09 ton, is thereby removed from the atmosphere per year. With respect to the
5 predetermined forested area, the rate of CO₂ removal from the atmosphere is generally greater than the rate of CO₂ release into the atmosphere. Thus, when continued through the years, the balance between the rate of CO₂ removal from the atmosphere and the rate of CO₂ release into the atmosphere will result in an atmospheric CO₂ level which is below the CO₂ level causing the undesired greenhouse effect.

10 A predetermined amount of the annually produced wood or charcoal may be used as an energy source by combustion; also, or alternatively, a predetermined amount of charcoal may be retrieved from the bunkering plant by conventional conveying means and may be used as an energy source by combustion. In any case, as long as the amount of CO₂ released thereby into the atmosphere does not exceed the amount of CO₂ which has been removed from the
15 atmosphere by means of the prior charcoal storage, the atmospheric CO₂ level will remain below the level which existed prior to the charcoal storage.

The rate of CO₂ removal from the atmosphere and the atmospheric CO₂ level are thus determined by the amount of biomass and biomass coal produced and stored within a given
20 time period in relation to the rate of CO₂ release into the atmosphere. The rate of CO₂ removal from the atmosphere and the atmospheric CO₂ level may also be agreed upon by an international convention such as the Kyoto Convention. In any event, the atmospheric CO₂ level can be maintained below the level, which will generate the undesired greenhouse effect, either by reducing the biomass or biomass coal utilization for generating energy by com-
25 bustion or, in the alternative, by increasing the amount of biomass, which is harvested and

converted into biomass coal, or by increasing the storage period of the thus produced biomass coal.

Example 2: In a publication entitled “Unser Wald” (“Our Forest”), published by the Bundesministerium für Ernährung, Landwirtschaft und Forsten (Federal Office of Food, Agriculture and Forestry), it is stated on pages 41 and 42 that 57 million m³ of wood were produced in the Federal Republic of Germany in 1997 by means of sustained forestry. The term “sustained forestry” is understood to imply that the amount of harvested wood is regrown between two successive harvesting operations. Of the produced 57 million m³ of wood per year, there were harvested only 38 million m³ and supplied for consumption. This amount of commercially produced wood has removed a corresponding amount of CO₂ from the atmosphere. A large portion of the harvested wood was further processed to yield wooden products and objects, which were not subject to combustion, while another portion was burnt for generating heat energy which resulted in concomitant release of CO₂ to the atmosphere. Thus, the wood processing industry and forestry contribute to the atmospheric CO₂ level in accordance with this relationship. In correspondence therewith, the atmospheric CO₂ level can be reduced if (a) the entire annual wood production of 57 million m³ is harvested and supplied for consumption without combustion whereby more CO₂ will be removed from the atmosphere by CO₂ assimilation, or if (b) the wood combustion is reduced so that less CO₂ will be released into the atmosphere. In fact, an additional amount of about 20 million m³ or more of wood is available to be harvested per year by means of sustained forestry and for conversion into charcoal which, then, is stored in accordance with Example 1. At a wood density of 0.66 kg/m³, there are annually available 13.2 million tons of wood which will yield 4.62 million tons of charcoal per year upon carbonization (0.35 tons of charcoal for each ton of wood, see Römpp, l.c.). The average carbon content of 85 percent by weight (see Römpp, l.c.) of this amount of annually stored charcoal corresponds to 3.93 million tons of pure carbon which is

the equivalent of 14.4 million tons of CO₂ which are annularly removed from the atmosphere by CO₂ assimilation during the wood regrowing process.

In a known wood carbonizer unit (Ullmann, Encyclopedia of Chemical Technology, 2003, vol. 16, pp 309, 310) for producing 100 kg of charcoal, the infed wood is pyrolyzed with an additional heat supply of 250 MJ and further by recycling the pyrolysis gas. Using carbon-rich fuel like heating oil for the additional heat supply, such heating oil has a gross calorific value of 45 MJ/kg (Brockhaus Encyclopedia 2003, vol. 3, p. 704) and contains 85 percent by weight of carbon. Consequently, 5.56 kg of heating oil are required for producing 100 kg of charcoal and contain 4.74 kg of carbon which, upon combustion, release 17.3 kg of CO₂ into the atmosphere according to stoichiometry. Furthermore, 286 kg of wood are required for producing 100 kg of charcoal and generate 49.2 kg of pyrolysis gas containing 12.7 kg CO₂, 8.8 kg carbon monoxide, 3.4 kg methane and 0.5 kg ethene (according to Römpp, l.c.) which, according to stoichiometry, respectively generate 13.8 kg, 9.35 kg and 0.8 kg of CO₂ on combustion. Accordingly, 36.7 kg of CO₂ will be released into the atmosphere as a result of recycling the pyrolysis gas.

Therefore, a total of 54 kg CO₂ are released into the atmosphere per 100 kg of charcoal produced during operation of the herein described carbonizer. Further amounts of CO₂, which are generated by Diesel driven harvesters and trucks during harvesting 286 kg of wood and transporting the same to the carbonizer are negligible in relation thereto.

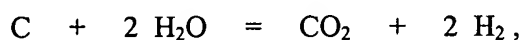
Considering that the aforementioned amount of 20 million m³ or 13.2 million tons of wood annularly available by sustained forestry are processed in a correspondingly dimensioned carbonizer described hereinbefore, there are obtained 4.62 million tons of charcoal containing 3.93 million tons of pure carbon (Römpp, l.c.). According to stoichiometry, this amount of carbon is the equivalent of 14.4 million tons of CO₂ which are annularly removed from the atmosphere first by the assimilation during growth of the wood and further as a result of the charcoal storage. This amount is to be corrected for the CO₂ amount released as a result of the

carbonization process, which generates 54 kg CO₂ per 100 kg of charcoal, i.e. an amount of 2.5 million tons of CO₂ per 4.62 million tons of charcoal. Consequently, the initially mentioned requirement is fulfilled, since the annual rate of CO₂ removal from the atmosphere, namely 14.4 million tons, exceeds the annual rate at which CO₂ is released into the atmosphere by the wood processing and charcoal storing operation, namely 2.5 million tons.

By continuing this process for a number of years, there will be achieved a balance in the rates of CO₂ removal from the atmosphere and the release of CO₂ into the atmosphere such that the atmospheric CO₂ level is below a level which causes the undesired greenhouse effect. Also, fractions of the stored charcoal may be retrieved and utilized as an energy carrier or an energy source with concomitant CO₂ release into the atmosphere, provided that the retrieved charcoal so utilized is limited to an amount which will not raise the atmospheric CO₂ level to a value above the annually removed amount of CO₂. Otherwise, the annual amount of wood to be harvested and processed to charcoal, would have to be increased in order to compensate for the excess in the CO₂ generation.

Example 3: A minor fraction such as 10% of the biomass coal or charcoal as produced and stored in accordance with Example 1 or 2, respectively, is reacted with water to form hydrogen which not only represents a very high energy fuel but particularly produces simply water upon combustion and thus is totally harmless to the environment or atmosphere.

The reaction of carbon and water according to the equation of reaction



however, is more complicated:

In a technical pressure reactor, there occurs first a highly endothermic carbon gasification according to



only at very high temperatures, which is followed at only moderately increased temperatures by the weakly endothermic "water gas shift reaction"



In order to achieve the required temperatures above 1500°C at the input of the pressure reactor for the coal gasification according to (1), a required amount of oxygen is admixed to the reactants water and finely divided carbon. There thus remain still about 83.4% of the coal to be processed for the production of hydrogen.

A typical Texaco plant for coal gasification (Kirk-Othmer, *ENCYCLOPEDIA OF CHEMICAL TECHNOLOGY* 3rd Ed. Vol. 12, Wiley, New York, pp. 959/960) having a capacity of $2.83 \times 10^6 \text{ m}^3/\text{d}$ of hydrogen is charged with 1,852 t/d of finely divided charcoal (of which 83.4% are process charcoal). Compared to all sorts of fossil coal, charcoal has the advantage of being free of any sulphur and heavy metal catalyst poisons whereby the useful life of the catalysts is prolonged and their efficiency is improved and any special gas purification operations become superfluous.

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The stored charcoal can be accessed for hydrogen production according to reactions (1) and (2) and, therefore, provides a foundation for a hydrogen economy based on solar energy. The hydrogen thus obtained preferably is fed to fuel cells for generating electrical energy. The combustion of hydrogen yields just water as an entirely harmless combustion product and a combustion energy (measured in Joule or BTU) per unit weight which is greater than the combustion energy of carbonaceous fuels by a factor in excess of 4. Therefore, the replacement of fossil carbonaceous fuels by hydrogen will result in a corresponding reduction in the use of fossil fuels. However, this favourable result is negatively affected by the high amount of CO_2 which is formed as a result of the sum of reactions (1) and (2). In fact, and according to the stoichiometry of reactions (1) and (2), the formation of 4 g of hydrogen requires the oxidation of 12 g of pure carbon plus 16.4 percent, i.e. 1.97 g of carbon for heat

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generation in reaction (1), resulting in the formation of a total of 51 g of carbon dioxide. This result places a limitation on the amount of charcoal used for this process in order to satisfy the aforementioned requirement of maintaining the balance between the rate of CO₂ removal from the atmosphere and the rate of CO₂ release into the atmosphere such that the CO₂ atmospheric level does not result in the undesired greenhouse effect. Otherwise, any excessive CO₂ release into the atmosphere may be compensated for by increasing the amount of harvested wood and the amount of stored charcoal or continuing the process of Example 2 through a longer period of time.

The aforementioned process may also be limited to reaction (1) for producing a mixture of carbon monoxide and hydrogen which mixture is commonly known as "synthesis gas". This synthesis gas is reacted by conventional, particularly catalytic, technical processes to form the most various oxygenated organic compounds for manufacturing industrial products for use in the most various technical fields. Thus, such industrial products are obtained from renewable sources without taking recourse to fossil raw materials like crude oil, natural gas or coal.

Again, the amount of charcoal introduced into the reactor for generating the additional heat required for carrying out reaction (1), may be limited so that the CO₂ release into the atmosphere satisfies the condition of preventing the undesired greenhouse effect. Also in this case, any undue increase in the atmospheric CO₂ level can be accounted for either by increasing the wood harvest and the amount of stored charcoal, or by continuing this process without alteration through a greater number of years.

In summary, the present invention will be seen to be concerned with eliminating the undesired greenhouse effect and is based on the recognition that the excessively high atmospheric CO₂ level is due to the material imbalance between the high rate of CO₂ release into the earth's atmosphere and the low rate of CO₂ removal from the earth's atmosphere. The

invention provides, at least for a limited geographical region, a method of reducing this material imbalance as well as the undesired greenhouse effect caused thereby. The inventive method achieves this control over the atmospheric CO₂ level (i) by using solar energy for assimilation of CO₂ and forming a corresponding amount of biomass in plants and (ii) by
5 converting harvested biomass into biomass coal and storing the same. Such process not only can be continued through a great number of years but also permits using limited amounts of stored biomass coal as an energy carrier or energy source with concomitant CO₂ release into the atmosphere. In the latter case, the released CO₂ can be recaptured (i) by correspondingly increasing the amounts of harvested biomass and stored biomass coal or (ii) by restricting
10 such use of the stored biomass coal to the required number of harvesting periods of unchanged amounts of biomass.

While there are shown and described present preferred embodiments of the invention, it is to be distinctly understood that the invention is not limited thereto, but may be otherwise
15 variously embodied and practiced within the scope of the following claims.

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